Utilization of FGD Products for High-Volume, High-Value Products in Underground Mines

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Introduction

The Appalachian coalfield of the eastern U.S. contains several billion short tons of "shut in" coal left behind in abandoned highwalls. Much of this coal has been auger mined and has unstable highwalls. This coal could be recovered by new automated highwall mining technologies, if the highwall could be stabilized. The most effective method to stabilize the highwall is by grouting. However, historically the costs of grouting have proven to be prohibitive.

Significant amounts of fluidized bed combustion material are now back hauled to the coalfields for disposal. These materials are cementitious and have the potential for use as grout. To be cost effective the materials must be able to be injected using simple delivery systems which achieve high ratios of recoverable coal to grout. The grout must also develop significant strength.

The development of highwall mining technology in the early 1990's altered the recovery potential of coal left beyond the highwall. The Joy-Addington Addcar™ highwall mining system (HWM) removes a rectangular coal panel of 3.5 m in width and up to 360 m in depth into the coal seam from the highwall. The highwall miner carries its own motivating power and is steerable with guidance provided by four television cameras on the front of the machine. The front of the system is a self-propelled continuous miner (Joy model 14CM15). Coal is carried away on a series of 12.2 m long cars, each equipped with a 1.07 m wide conveyer belt, which are added with a launch vehicle that also pushes the miner. Each belt-car has its own motor at the head of the car, and the belt drive also raises and lowers the belt to allow coal to cascade onto the next car in line. All personnel remain on the surface, as the operation is controlled remotely[1].

Highwall mining systems have become very popular since their introduction and there are currently dozens of systems in operation in the U.S. and Australia. They can recover coal which was previously unmineable, such as under keyways and in areas with limited reserves.

Objective

The ultimate objective of this project is to assess the technical and economic feasibility of using grout produced from fluidized bed combustion (FBC) ash (fly ash and bed ash) to backfill highwall auger holes, allowing for recovery of the "shut-in" coal. This will provide an economic use for a material which is currently landfilled. The technology will add significantly to the reserves of high quality recoverable coal in the Appalachians.

Approach

The project is divided into two phases: 1) laboratory investigations and site characterization; and 2) field demonstration of the technology at a mine site. The laboratory investigation phase of the project comprised chemical and mineralogical testing of the FBC ash, determination of geotechnical properties, and design of an optimum grout mix. The field experiments were designed to study the handling and emplacement characteristics of both the the AFBC bed ash and fly ash and to determine requirements for site preparation. Different types of concrete/grout pumps were also evaluated. This paper focuses on the results of the field demonstration and analysis of grout samples, obtained from the mine site, although some results of the laboratory work are also discussed.

Project Description

Results of Laboratory Work

Physically, the AFBC spent bed material, or "bed ash", has the consistency of coarse sand. It typically constitutes about 15 to 20% of the total solids output. The AFBC cyclone/baghouse catch, typically referred to as "fly ash", is much finer and makes up the bulk of the waste.[2]

Dry-FGD wastes are known to be cementitious when used with water, and can produce high strength material with sufficient curing. The presence of free and hydrated lime along with glassy alumino-silicates is, of course, responsible for this. The reactions and minerals formed are quite different from that of portland cement. In portland cement the recommended range of $CaSO_4$ content is 2 to 4%, much lower than the amount of $CaSO_4$ in dry FGD materials. The large amount of sulfates in the LIMBs and PFBC materials reacts with the slaked lime (or portlandite, ($Ca(OH)_2$)) to form calcium sulfoaluminates, the most important mineral of this group being ettringite:[3]

$$6Ca^{2+} + Al^{3+} + 3SO_4^{2-} + 12OH^- + H_2O \rightarrow Ca_6Al_2(SO_4)_3(OH)_{12}\cdot 26H_2O$$

A pH of 12 or above is required for ettringite formation, a condition readily supplied by $Ca(OH)_2$. Late stage or secondary ettringite is not considered to be desirable in normal portland cements.

The extensive laboratory investigations conducted for this project demonstrated that, as in the case of portland cement grouts, the compressive strength of the grout is strongly influenced by the water content of the mix.[4] Moisture controls the void volume (porosity) and bulk density. Increasing the water content of the grout to improve its ability to flow, therefore, causes a decrease in compressive strength.

Laboratory work demonstrated that high temperatures accelerated the curing of the AFBC based grout. This is similar to portland cement and potentially allows for coal recovery relatively soon after the grouting operation. Although the ambient temperature within the auger holes is only about 16 ^{o}C, the holes insulate the grout during setting. This results in a higher actual curing temperature because of the exothermic hydration reactions occurring in the large volume of material.

Finite element analysis of the mine system indicated that a compressive strength of 500 PSI would be sufficient for competent roof support during re-mining. The material must also display good stiffness. Unconfined compressive strengths of 500 PSI in combination with sufficient flowablity to fill a 100+ foot long auger hole was the target criteria for the field trials.

The Field Demonstration

Field Site 1-Test Series 1 and 2

Test Series 1 and 2. The field demonstration included five test series at two different locations. Test Series 1 and 2 were conducted in October of 1996 on auger holes located at the Sunny Ridge Co. Job 20 site in Floyd County, Kentucky. The first location was well above the access road and the job site was relatively dry.

An access road was graded to the site of the auger holes and a bench created. The holes were then uncovered with a bulldozer and the remaining rock debris was shoveled out by hand. The auger holes were 0.8 m in diameter and varied in depth from ~20 m to 30 m. Each hole was separated by a coal web of between 0.2 and 0.3 m in thickness.

The depth of each hole was measured by sliding 4 cm diameter water PVC pipe in the holes. The depths were also checked with a camera mounted on a skid made from 2 cm PVC pipe attached to a 8 cm diameter PVC pipe.

The equipment utilized for the grout emplacement consisted of two concrete mixing trucks of 7.6 m^3 capacity. These were charged with FBC conditioned fly ash at the Lodestar Energy Inc. railway load-out facility in Ivel, Kentucky (Floyd County), located approximately 8 km from the job site. Portable truck scales were used to monitor the water added to the trucks and the slump of the grout mix was also monitored. The grout mix was driven to the job site and used to supply a concrete pump truck. The water was added at the mine site using the mine's dust suppression tank truck. The delivery system consisted of a Morgan positive displacement (piston) pump capable of delivering up to 87 m^3 per hour of concrete. The truck used 13 cm diameter high-pressure hose and high strength steel pipe. These were mated to 10 cm diameter ASTM schedule 40 PVC pipe. This pipe was obtained in 6.1 m long sections and connected with glued ASTM schedule 80 unions.

The objectives of the first two test series were to examine the pumping and flow characteristics of the grout and also to examine bulkhead options. The grout was put in at a high water content (~38-40% moisture) and it was determined that the grout could be pumped the length of the auger holes, the longest of which was 87 m. The second test series was run at lower moisture

(~35-37%) to determine if a high strength grout could be created by injecting the material under pressure. The tests indicated that the material could be formulated to completely fill the auger hole and that sandbags could be used to construct an effective bulkhead.

A number of difficulties were encountered during the first two tests. Two cement trucks did not provide materials fast enough, and adding moisture at the mine also proved to be too slow. Waiting too long resulted in the grout stiffening in the pipe which would then fail (typically at joints) due to high pressures needed to clear the pipe. The crust which forms at the top of FGD material in the rail cars also got trapped in the pipes, particularly at the 13 cm to 10 cm reducing bushing, causing failure. The portable truck scales did not prove to be accurate when used on mine haul roads.

Solutions to these problems incorporated into the next series of tests included: the addition of a third cement mixer; bolting and solvent welding critical pipe joints; ASTM Schedule 80 PVC piping was used in place of Schedule 40; and pipe connections were changed to Victaulic couplings from threaded unions.

Field Site 2, Test Series 3, 4 and 5.

<u>Test Series 3.</u> The second field site was prepared by Lodestar Energy, Inc. and was located within 0.8 km of the first. A total of twenty-three auger holes were uncovered during site preparation.

The holes were located approximately 15 m from an active haul road and were below the road grade, which caused the area directly in front of the holes to fill with water. All of the auger holes dipped away from the entrance, and were, therefore, full of water towards the back. This water was pumped out so that the holes could be surveyed.

Four auger holes were filled with grout during the third test series. All of the tests were more or less successful. The sandbag bulkheads held and allowed for most of the auger holes to be filled and contact with the roof to be established. However, it was clear that the sandbags would not support much pumping pressure and they did allow some of the grout to slump forward. The best results were obtained with an earthen embankment, which enabled pressure to be applied and facilitated a complete fill. This test series also clearly established that the grout could be successfully emplaced without the use of superplasticizers, which were employed earlier in the study.

<u>Test Series 4</u>. Test series four focused on the use of progressive cavity or moino pumps. This style pump is commonly used in underground mine grouting as it is comparatively light and powerful. An 11 kw underground unit was utilized in the experiments. This pump was capable of delivering grout at a rate of ~7.6 m^3/hr. The pump could deliver grout at high speed through 3.1 cm diameter piping. The objective of this test was to see if it could be used to deliver low moisture grout to fill gaps left at the top of the piston pump fills, or possibly be used instead of the piston pump. The FGD material was delivered with low water content (~8% moisture) and additional water was added at the mine site from a pond made for the purpose. The final moisture content was in the range of 32% to 35%.

Test series four was met with mixed results. It was determined that grout could be delivered at low moisture (~34%). However, the small diameter pipe used was easily clogged. The pump used also proved to be too fragile for this application.

Table 1. Summary of Data from Field Grout Tests.

Sample I.D.	Sample Moisture (wt.%)	Compressive Strength (PSI)	Wet Density (g/cm^3)	Dry Density (g/cm^3)	Sample Void Ratio
L1	30.4	944	1.56	1.09	1.48
L2	34.3	1334	1.61	1.06	1.55
L3	40.0	1000	1.67	1.02	1.66
L8	38.7	1597	1.59	0.98	1.76
L10	36.7	1601	1.60	1.01	1.66
R2	34.1	2263	1.79	1.18	1.29
R4	39.5	1677	1.79	1.08	1.50
R11[2]	38.9	1759	1.58	0.97	1.80
R12[2]	35.9	1706	1.55	0.99	1.72
R13	36.5	1602	1.94	1.24	1.19

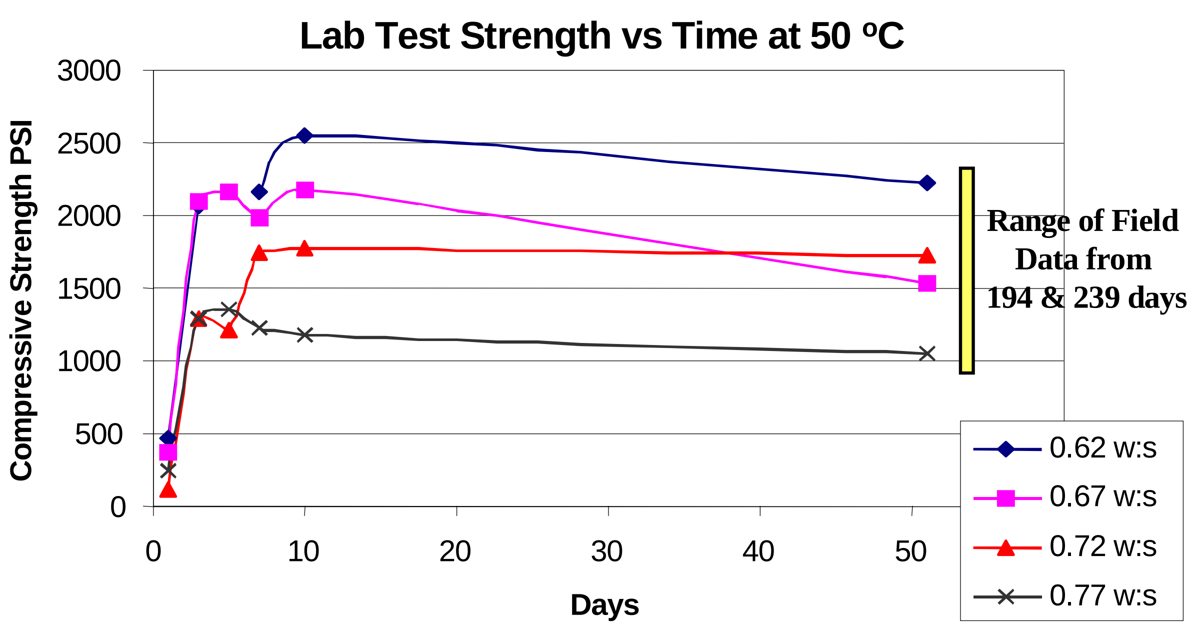

Figure 1 Plot of laboratory strength data versus range of data observed for field samples.

Test Series 5. The final test series centered on using bed ash as a grout. A few additional tests on the effect of moisture on pumping were also made. Hydrating and cooling the bed ash were the largest problem encountered in this experiment. Water was added to the cement mixer trucks to first hydrate and then cool the material. However, the bed ash showed delayed hydration characteristics and several cycles of water addition followed by heating and cooling was necessary. The bed ash required about 1/3 more water than the fly ash to reach the same slump, much of the difference was probably due to evaporative loss. The bed material was successfully installed in two of the auger holes.

Results of the Field Demonstration

The auger holes at the second field site were mined through in February of 1998. Project personnel were able to recover samples for evaluation. Geotechnical, chemical, and mineralogical testing was conducted. All of the grouts were found to have very good mechanical strength, ranging from 1000 psi to 2250 psi (Table 1).

This range of strengths is in excellent agreement with laboratory data (Figure 1). The lowest compressive strength was recorded on an FBC bed ash-based grout (Table 1 Sample L1), which contained significant amounts of gypsum (Gp) and portlandite (Pt), in addition to ettringite (Et), quartz (Qz), calcite (Cc) and gehlenite (Ge). In contrast, the fly ash-based grouts were generally stronger and contained little or no gypsum and/or portlandite (Figure 2).

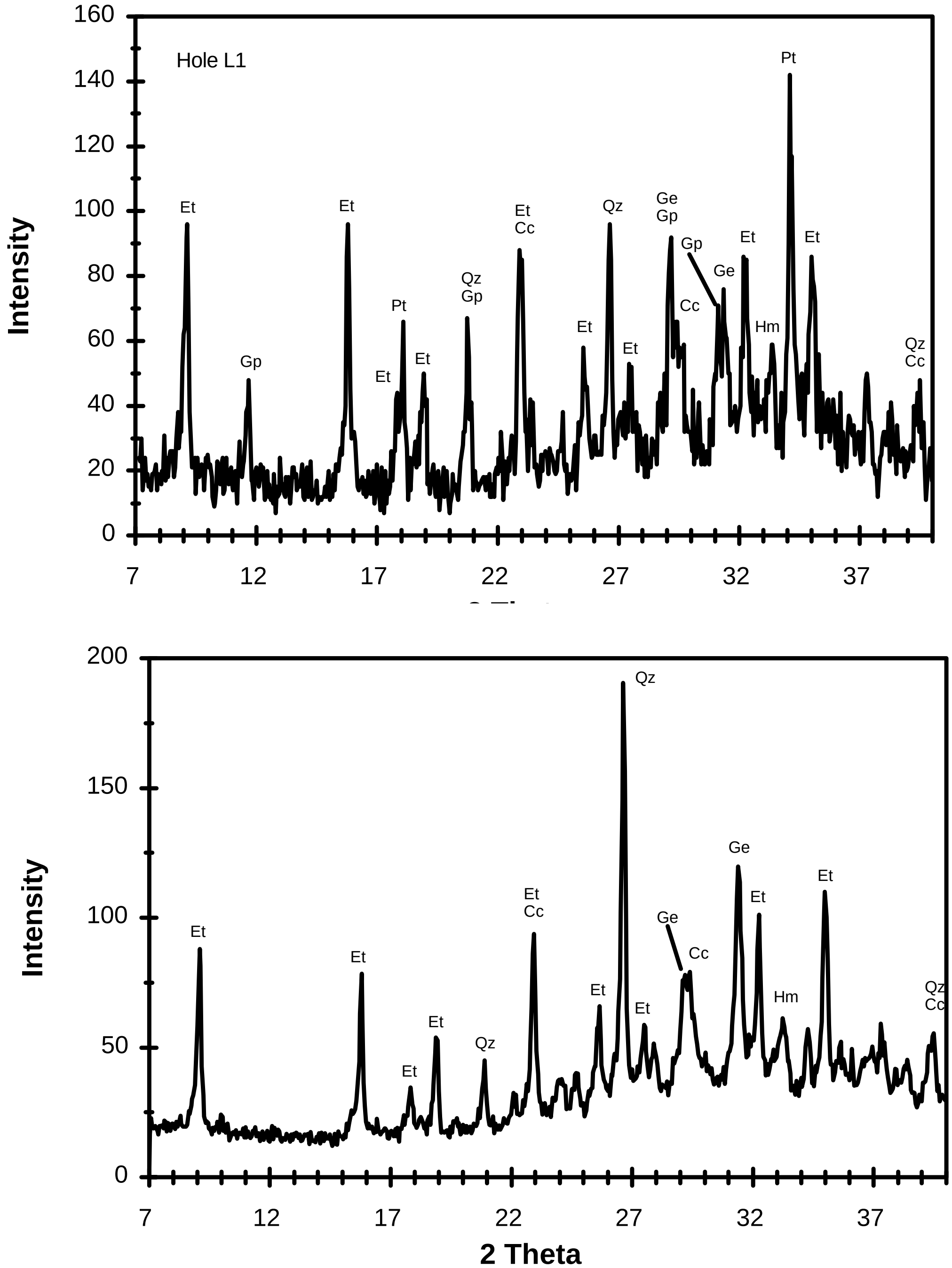

Figure 2. XRD spectrum of FBC fly ash grouts. The upper figure is from AFBC Bed ash material, the lower is from AFBC fly ash.

Conclusions

The following conclusions can be made based upon the field demonstration:

- the AFBC material could be used to formulate a grout with sufficient pumpability to fill the length of a typical auger hole.

- even the grouts which contained the highest moisture contents developed strength which was well beyond the minimum criteria for the application.

- suitable grouts could be made from both the AFBC bed ash and fly ash, although the high heat release from the bed ash made this material more difficult to condition and handle

- the grout could be delivered using conventional pumps as currently employed to pump concrete

- pumping the grout required robust equipment; moino style grout pumps failed repeatedly during the tests

- simple earthen bulkheads were adequate to control the injection and allow the complete filling of the auger holes

- grouting could be conducted with minimal manpower

- high ratios of coal recovered to grout emplaced could be achieved (i.e. 15:1 to 35:1)

- preliminary economic analysis indicates that the technology is viable at least for premium coals

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